HRRR summer 2015 Evaluation

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1. Introduction

For 2015 a wide-ranging set of enhancements were made to improve the HRRR (and RAP) forecast performance. The changes to the RAP / HRRR system have resulted in significant forecast enhancement for both models. In this document, we have included a description of the RAP changes because they significantly impact the HRRR forecasts and because many of the changes (especially model physics changes) are made to both model systems. A principal focus of the enhancements made for 2015 has been to reduce the near-surface warm season warm / dry bias in the afternoon and evening, that is evident in the NCEP operational HRRR (effectively the summer 2013 GSD experimental HRRR) and was to a lesser degree evident in the 2014 GSD real-time experimental HRRR. In addition to affecting surface temperature and dewpoint values, this bias impacted HRRR convective development, resulting in instances of excessive convective development too far south into the warm sector region of larger-scale systems. The mechanism for this convective impact appears to be the deeper, more well-mixed boundary layer and associated reduction of the model capping inversion. Other changes included increasing the weight of global ensemble background error covariance (BEC) relative to the regional 3DVAR BEC, resulting in an improvement in upper-level verification scores. It is important to note that relative to the current NCEP operational HRRR, the operational implementation planned for fall 2015 will include upgrades from the past two seasons in the GSD real-time experimental HRRR. In this note, we describe the combined set of changes from RAPv2 / HRRRv1 (the current NCEP operational RAP/HRRR) to the RAPV3/HRRRv2, with the specific changes described in section 2, followed by the presentation of selected verification in section 3.

2. RAP / HRRR changes for 2015

Two significant run configuration changes were made to the RAP and HRRR for 2015. First, the RAP domain was expanded, with coverage matching the NAM model. This will greatly facilitate the construction of ensembles, and is shown in Fig. 1. The expanded domain also increases the area over which satellite data (especially polar orbiter data) can be assimilated, allowing for more effective bias correction of these data and potentially improved forecasts.

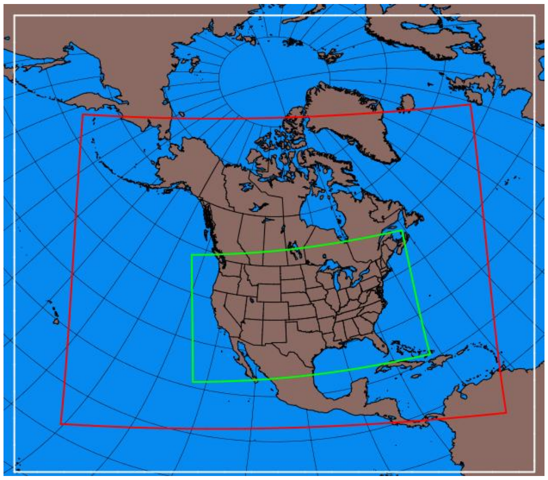

Fig. 1. Expanded RAP domain (white), earlier RAP domain (red), and HRRR domain (green)

A second key change was the increase in the forecast length for the RAP and HRRR. The GSD real-time experimental RAP is now running out to 30 hours and the HRRR out to 24 hours. While there will also be a forecast length increase for the next NCEP operational RAP/HRRR implementation, the respective run length increases will be somewhat less (likely just to 18-h forecast length for the HRRR).

The bulk of the changes were focused on improving forecast skill and are summarized in Table 1. In the bottom block, items shaded in red are upgrades to the RAP / HRRR system for the 2015 GSD warm season evaluation. In addition to the RAP domain expansion, described above, there

Table 1. System configuration summary for RAPv2/HRRRv1 in top panel and RAPv3/HRRRv2 in bottom panel. Items shaded red in the bottom panel are changes.

Operational RAPv2 and HRRRv1

Model	Run at:	Domain	Grid Points	Grid Spacing	Vertical Levels	Pressure Top	Boundary Conditions	Initialized
RAP	GSD, NCO	North America	758 x 567	13 km	50	10 mb	GFS	Hourly (cycled)
HRRR	GSD, NCO	CONUS	1799 x 1059	3 km	50	20 mb	RAP	Hourly (pre-forecast hour cycle)

Model	Version	Assimilation	Radar DA	Radiation LW/SW	Microphysics	Cumulus Param	PBL	LSM
RAP	WRF-ARW v3.4.1+	GSI Hybrid 3D-VAR/Ensemble	13-km DFI	RRTM/ Goddard	Thompson v3.4.1	G3 + Shallow	MYNN	RUC
HRRR	WRF-ARW v3.4.1+	GSI 3D-VAR	3-km 15-min LH	RRTM/ Goddard	Thompson v3.4.1	None	MYNN	RUC

Model	Horiz/Vert Advection	Scalar Advection	Upper-Level Damping	6^{th} Order Diffusion	SW Radiation Update	Land Use	MP Tend Limit	Time-Step
RAP	$5^{th}/5^{th}$	Positive-Definite	w-Rayleigh 0.2	Yes 0.12	10 min	MODIS Fractional	0.01 K/s	60 s
HRRR	$5^{th}/5^{th}$	Positive-Definite	w-Rayleigh 0.2	No	5 min	MODIS Fractional	0.07 K/s	20-23 s

RAPv3 / HRRRv2 – 2015 Changes

Model	Run at:	Domain	Grid Points	Grid Spacing	Vertical Levels	Pressure Top	Boundary Conditions	Initialized
RAP	GSD, NCEP	North America	953 x 834	13 km	50	10 mb	GFS	Hourly (cycled)
HRRR	GSD, NCEP	CONUS	1799 x 1059	3 km	50	20 mb	RAP	Hourly (pre-forecast hour cycle, LSM full)

Model	Version	Assimilation	Radar DA	Radiation LW/SW	Microphysics	Cumulus Param	PBL	LSM
RAP	WRF-ARW v3.6+	GSI Hybrid 3D-VAR/Ensemble to 0.75	13-km DFI + low reflect	RRTMG/RR TMG	Thompson – aerosol v3.6.1	GFO v3.6+	MYNN v3.6+	RUC v3.6+
HRRR	WRF-ARW v3.6+	3km: GSI Hybrid 3D-VAR/Ensemble to 0.75	3-km 15-min LH +low reflect	RRTMG/ RRTMG	Thompson – aerosol v3.6.1	MYNN PBL Clouds	MYNN v3.6+	RUC v3.6+

Model	Horiz/Vert Advection	Scalar Advection	Upper-Level Damping	6^{th} Order Diffusion	SW Radiation Update	Land Use	MP Tend Limit	Time-Step
RAP	$5^{th}/5^{th}$	Positive-Definite	w-Rayleigh 0.2	Yes 0.12	20 min	MODIS Fractional	0.01 K/s	60 s
HRRR	$5^{th}/5^{th}$	Positive-Definite	w-Rayleigh 0.2	Yes 0.25 (flat terr)	15 min with SW-dt (Ruiz-Arias)	MODIS Fractional	0.07 K/s	20 s

are numerous modifications to model physics and data assimilation. Some key changes are highlighted here in the test. As noted above a broad set of enhancements was made to various model physics components (land surface model, boundary layer scheme, RAP cumulus parameterization) to address the warm / dry bias. Within previous RAP / HRRR versions, this bias was evident not only in the surface temperature and dewpoint errors, but also comparison of HRRR insolation with that from SURFRAD sensors (not shown). The resultant package of changes is summarized in Table 2. Key changes were the inclusion of a boundary layer cloud scheme, coupled to the radiation scheme. Another key change was to begin fully cycling the HRRR land surface fields.

Table 2. Specific changes to the RAP / HRRR systems for 2015 (and for the NCEP RAPv2 / HRRRv3 operational system planned for fall 2015) that address the warm dry bias, listed by model component.

Component	Mitigating Items
GSI Data Assimilation	Canopy water cycling Temp pseudo-innovations thru model boundary layer More consistent use of surface temp/dewpoint data
GFO Convective Parameterization	Shallow cumulus radiation attenuation Improved retention of stratification atop mixed layer
Thompson Microphysics	Aerosol awareness for resolved cloud production Attenuation of shortwave radiation
MYNN Boundary Layer	Mixing length parameter changed Thermal roughness in surface layer changed Coupling boundary layer clouds to RRTMG radiation
RUC Land Surface Model	Reduced wilting point for more transpiration Keep soil moisture in croplands above wilting point

Other key changes were to the data assimilation. For the RAP, the weighting of the global ensemble BEC was increased from 50% to 75%, with the static BEC decreasing from 50% to 25%. For the HRRR analysis (applied at the end of the hour pre-forecast), the BEC was switched from being entirely static to 75% global ensemble.

3. RAP and HRRR forecast skill for 2015

Overall RAP and HRRR forecast performance is significantly improved for 2015 as revealed by a variety of statistical and case study assessments. We present here just a few selected results that highlight the widespread improvement. Fig. 2 shows a comparison RAPv3 vs. RAPv2 RMS and bias errors for 12-h forecasts of surface temperature, dewpoint, and wind (measured relative to METAR observations) from a retrospective test. The significant reduction in both the RMS and bias errors is evident for all three fields. Similar improvement is also seen for the HRRRv2 forecasts relative to the HRRRv1.

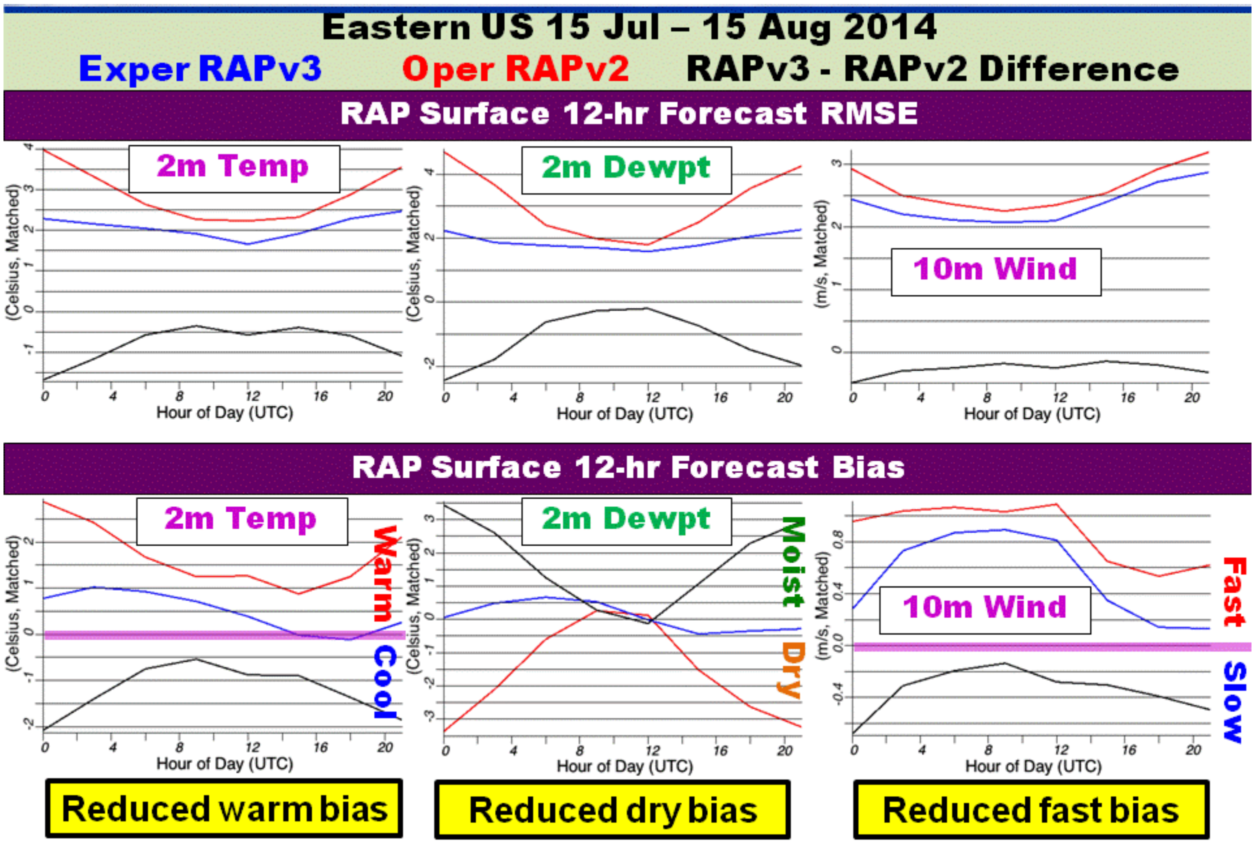

Fig 2. Comparison of HRRR forecast reflectivity CSI scores (30 dbz, 3-km native grid)

Fig. 3 shows a comparison of matched experimental HRRRv2 reflectivity skill scores vs. the operational HRRRv1 for the period May 1 through Oct. 31, 2015. Examination of the plots shows an increased CSI for the HRRRv2 for shorter lead times and a reduction in the high bias to values closer to 1 (depicted as "100" in the plot) for the entire forecast period. This reduced bias is especially significant, indicating the HRRRv2 has fewer instances of spurious convection compared to the HRRRv1.

Fig. 4 shows an example of the manifestation of the high bias in the HRRRv1, a significant overprediction of convection in the HRRRv1 and the marked improvement evident in the HRRRv2. As can be seen, the 6-h HRRRv1 forecast spuriously predicts the development of a significant line of storms across western Kansas, whereas the HRRRv2 restricts convective development to the OK and TX panhandles. We note that for most cases the convective differences between the HRRRv1 and HRRRv2 were much less, but this example provides an illustration of how the HRRRv2 is a significant improvement for the occasional occurrence of major HRRRv1 convective overprediction.

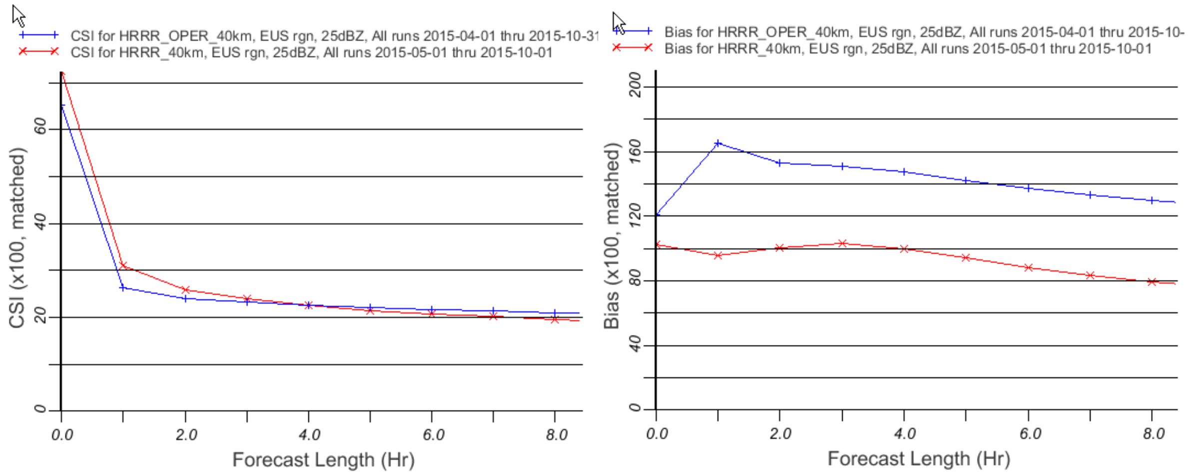

Fig 3. Comparison of CSI (left) and bias (right) for real-time experimental HRRRv2 (red curves) and operational HRRRv1 (blue curves) forecast reflectivity (20 dbz, 20-km grid, Eastern U.S.) as a function of forecast lead time.

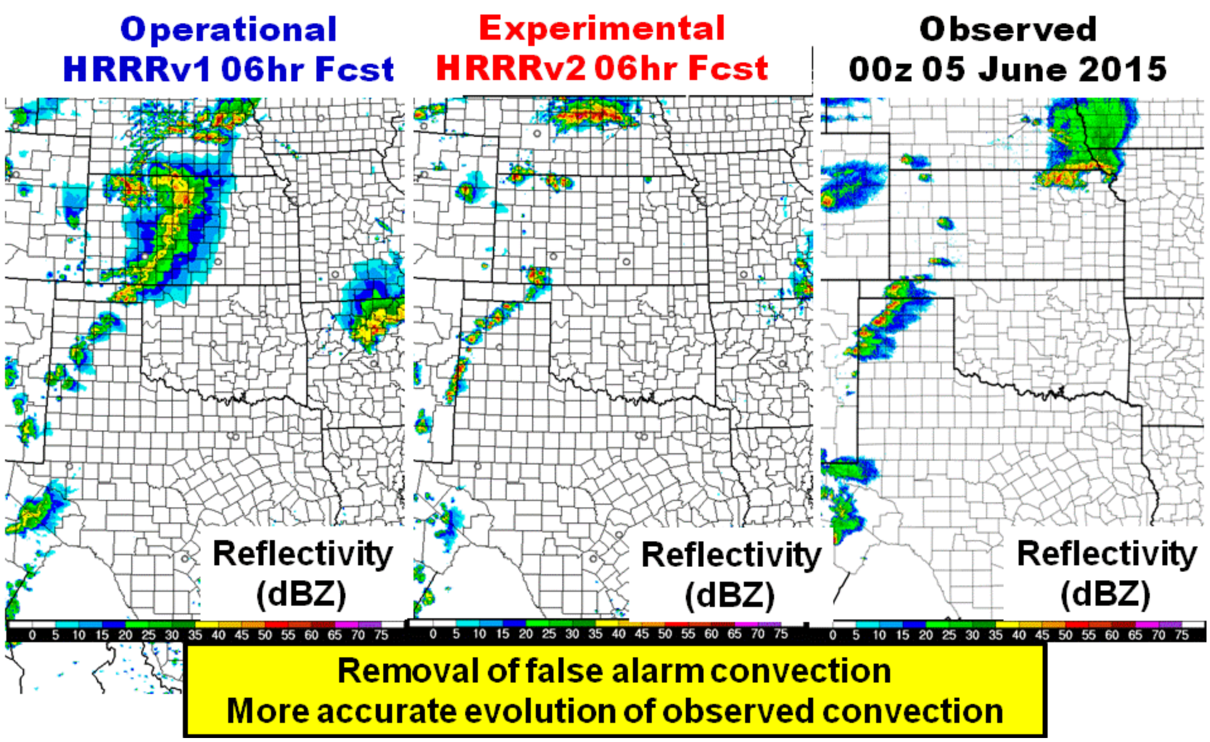

Fig. 4. Radar observed (right) and real-time forecast reflectivity from operational HRRRv1 (left) and experimental HRRRv2 (center) for thunderstorms on June 5, 2015. The significant improvement of the HRRRv2 over the HRRRv1 in avoiding the spurious convection over western KS is quite evident.

The slight degradation in HRRRv2 CSI scores compared to HRRRv1 at the longer lead times is linked with the bias decreasing below 1 (“100” in the plot) for the later hours and the CSI metric favoring a somewhat high bias. Qualitative examination of many forecasts indicates much better storm location, coverage, and especially structure (better depiction of isolated vs. linear storms, etc.) in the HRRRv2 compared to the HRRRv1. Based on this assessment, adjustments to HRRRv2 reflectivity parameters have been made that will address this low bias.

NCEP operational implementation of this improved RAPv3 / HRRRv2 system is planned for April. 2015 and work is progressing at GSD on enhancements for the next RAP/HRRR version, including a focus on storm-scale ensemble data assimilation in the HRRR.